Dioryctria zimmermani (Grote)

THE ZIMMERMAN PINE MOTH

An 8-year study of its natural history in Illinois coniferous plantations

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Bulletin 660

University of Illinois · Agricultural Experiment Station

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Cover photo by William E. Clark, Illinois State Natural History Survey

Urbana, Illinois May, 1960

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

THE ZIMMERMAN PINE MOTH

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THE PRESENT AND POTENTIAL FOREST LAND comprises approximately 17 percent of the 35.8 million acres in Illinois. Ninety-five percent of this forest acreage is privately owned and consists of small parcels that are a part of operating farms scattered throughout the state.

The potential forest land in Illinois, by conservative estimate between 2½ and 3 million acres, is largely worn-out and badly eroded farmland judged to be better suited for growing trees than for any other purpose. This depleted land is being planted primarily to coniferous trees, most of which are not native to the localities where they are being planted.

As the planted acreage increases and the distance between established plantations decreases, the occurrence in outbreak proportions of destructive forest insects may be expected. Such an outbreak may result not only in substantial economic loss to individual landowners, but by deterring the reforestation program may indirectly affect the economy and well-being of the people of the entire state. It is hoped that through intensive investigation of potentially serious forest insects, preferably in advance of their occurrence in epidemic numbers, heavy losses may be averted.

PURPOSE OF THE STUDY

The Zimmerman pine moth, *Dioryctria zimmermani* (Grote)[1], has been a serious pest of pines since its discovery in the United States in 1877. In several instances it has reached outbreak proportions and has caused much concern in many localities within its range.

NOTE: The figures in parentheses below and elsewhere in this bulletin refer to literature cited.

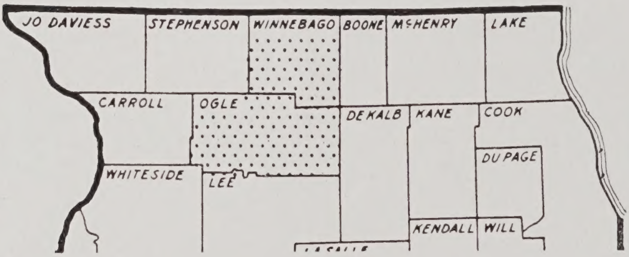
[1] The Zimmerman pine moth is a member of the family Phycitidae. It was described by Grote (12) and assigned to the subgenus *Dioryctria* of the genus *Nephopteryx* and was given the specific name *zimmermani*. Since then it has been known by the following names that Heinrich (14) considered synonomous with *Dioryctria zimmermani* (Grote): *Nephopteryx (Dioryctria) zimmermani* Grote (12); *Nephopteryx (Pinipestis) zimmermani* (Grote) (13, 20); *Pinipestis zimmermani* (Grote) (13); *Nephopteryx zimmermani* Grote (19); *Dioryctria zimmermanni* Grote (23); *Pinipestis zimmermanni* (Grote) Hulst (16, 20); *Salebria delectella* Hulst (17, 24); *Dioryctria delectella* (Hulst), Dyar (10); *Retinia austriana* Cosens (6, 4); *Pinipestis delectella* (Hulst) (1); *Dioryctria ponderosae* Heinrich (14); and *Dioryctria zimmermani* (Grote) (14, 8).

The study here reported was conducted from 1951 through 1958 in central and northern Illinois at a time when the moth population was extremely high. A review of the literature revealed that, although this pest had been studied by a number of entomologists, knowledge of its biology and ecology was incomplete. The purpose of this study has been to fill these gaps in the hope that a more complete understanding of its life history and environmental interactions would indicate how forest plantations infested by this insect can be managed to reduce injury to the trees.

The study has been divided into two phases: the first to verify the insect's seasonal history, as reported in the literature, and to add to our knowledge of its habits; and the second to determine the environmental influences that affect its abundance. The work during 1951 through 1954 was devoted primarily to studying the distribution and biology of the moth in Illinois. From 1955 through 1958, pine plantations were examined to assay some of the principal ecological conditions characteristic of infested and uninfested trees and stands.

LOCATION AND DESCRIPTION OF THE AREA STUDIED

The moth was observed and collected wherever it could be found in central and northern Illinois. From this extensive study much information was gathered concerning its seasonal history.



Location of the area intensively studied. (Fig. 1)

More intensive studies were concentrated in Winnebago and Ogle counties in the northwestern part of the state (Fig. 1). These two counties, lying in the drainage basin of the Rock river, cover about 808 square miles. The topography ranges from steeply rolling to gently rolling terrain. Glaciation contributed to the land configuration. The soils are mostly loessal or water-deposited materials that, in most places, cover the glacial drift. Elevations range from 685 to 990 feet in Winnebago and from 700 to 931 in Ogle county.

The predominant land use is general agriculture and dairying. Therefore most places have been tilled at one time or another. Slope and productivity ratings, however, indicate that 13.9 percent of Winnebago and 8.0 percent of Ogle county are better suited for growing timber than other crops. According to the most recent estimate of forest acreage in these counties, there are 51,000 acres in farm woodlands. This figure includes 2,000 acres of forest plantations, largely coniferous. As only a few white pines were native to northern Illinois, all other pines in this part of the state are planted and are outside their natural range. Their insect pests have frequently been introduced with them. This is true of the Zimmerman pine moth.

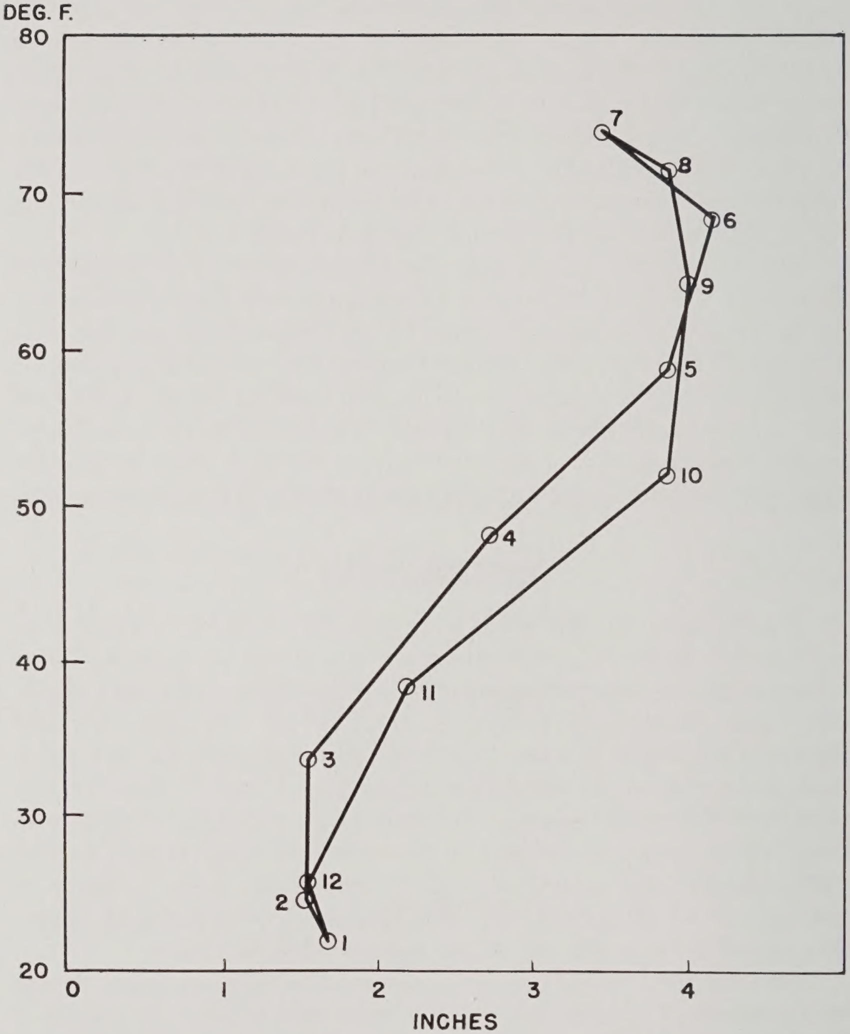
Weather records collected in Winnebago county at Rockford, Illinois, from 1941 to 1957 indicate temperature conditions characteristic of the region. The greatest range of temperature for any one year was 123° F. in 1947. The highest temperature recorded was 103° F. in 1947; the lowest, −25° F. in 1950. The average annual rainfall for this portion of Illinois is 34.4 inches. Average monthly rainfall and temperature are shown in the climatograph in Fig. 2. This graph indicates that the bulk of precipitation occurs during the summer months.

DISTRIBUTION

The Zimmerman pine moth is presumably a native species. It is known only in the United States and Canada and is generally found wherever its favored hosts occur. Grote (12), Zimmerman (27), Kellicott (19), Packard (21), Cosens (7), Britton (2), and Felt and Rankin (11) report it from New York, Pennsylvania, the New England states, Michigan, and from Ontario in Canada. Brunner (3) states that it is rather generally distributed over the range of ponderosa pine (*Pinus ponderosa* Dougl.) in the western United States. Polvika (22), Houser (15), and Chadwick (5) studied the insect in Ohio. In the opinion of Craighead (8) and Heinrich (14), this pest occurs throughout most, if not all, of the northern United States.

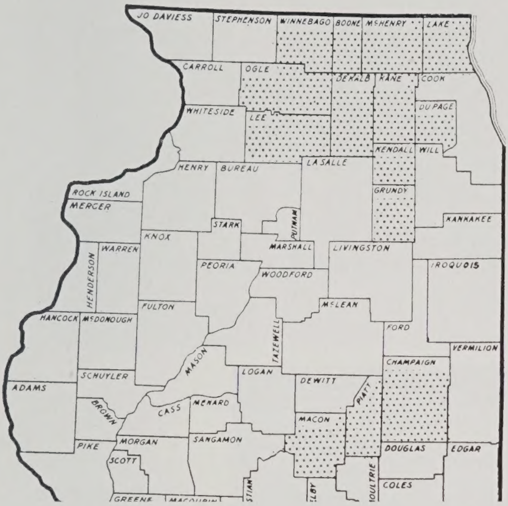
Prior to 1942 it had not been observed in Illinois. Then it was found attacking Scotch pine (*Pinus sylvestris* Linnaeus) and, to a lesser extent, other pine species near the town of Oregon.

Correspondence at that time with other entomologists in Michigan, Wisconsin, Indiana, Iowa, and Kentucky failed to reveal any localities in those states where the insect was causing appreciable damage. Since then, however, Schuder (25) has reported an outbreak in northern Indiana, and Shenefelt and Benjamin (26) discussed in some detail the presence of the moth and its damage to pines in Wisconsin. In



Mean climatograph for Rockford, Illinois, based on monthly temperatures and precipitation. Numbers indicate the months of the year. (Fig. 2)

Illinois (Fig. 3) field inspections have disclosed its presence in planted pines in 14 counties in the northern and central parts of the state.



Known distribution of the Zimmerman pine moth in Illinois. (Fig. 3)

CONDUCT OF THE STUDY

Cage Experiments

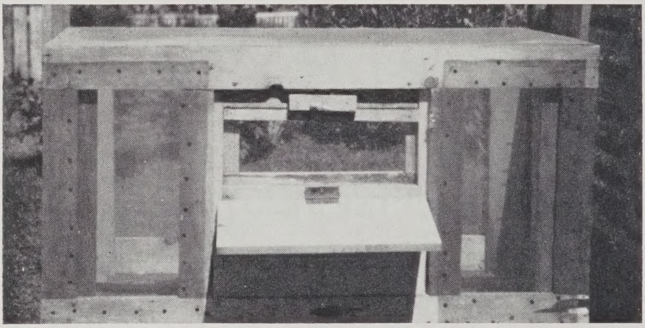
A wire-screen covered cage (Fig. 4) $4\frac{1}{2} \times 4\frac{1}{2} \times 14$ feet at Philo, Illinois, served as an outdoor laboratory from 1952 through 1957. It enclosed 4 pines — 3 Austrian (*Pinus nigra* Arnold) and 1 red pine (*Pinus resinosa* Aiton). In 1958 another wire-screen covered cage (Fig. 5) $1\frac{1}{2} \times 2 \times 4$ feet suspended from the joists of the loft floor of an open driveway in a barn was used instead.

Larvae and pupae of the moth were collected by careful use of a knife after the resin masses were removed. Only larvae that had completed feeding and were ready to pupate were collected. Observation on moths that had emerged from these field collections provided information concerning emergence, sex ratio, copulation, oviposition, and parasites.

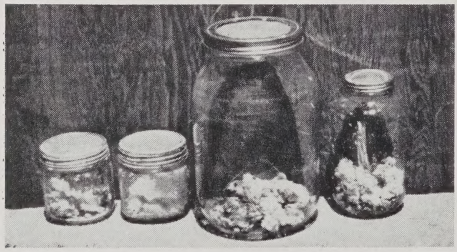
Larvae and pupae were transported from the field to the laboratory in wire-screen covered glass jars (Fig. 6). Similar jars prior to 1958 were used as isolation chambers for mated females in oviposition studies.

In the 1958 oviposition studies, screen-wire cages (Fig. 7) were attached to tree trunks and limb sections with friction tape and small

Open-air screened cage used in the study through 1957. (Fig. 4)

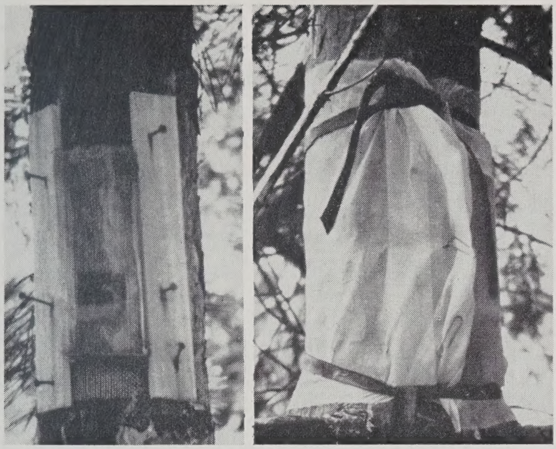


Screened cage used in 1958. (Fig. 5)



Glass jars with screen-wire lids used for making field collections and for isolating mated females. (Fig. 6)

wooden slats. These cages, which were $1 \times 2 \times 6$ inches, were used as confinement chambers for mated females. Tight mesh cloth sleeves (Fig. 7) secured at the top and bottom with heavy rubber bands were used in an effort to get information on oviposition under more nearly natural conditions.



(Left) screen-wire confinement cage on a Scotch pine. (Right) cloth sleeve covering on an artificially infested Scotch pine. (Fig. 7)

Field Experiments

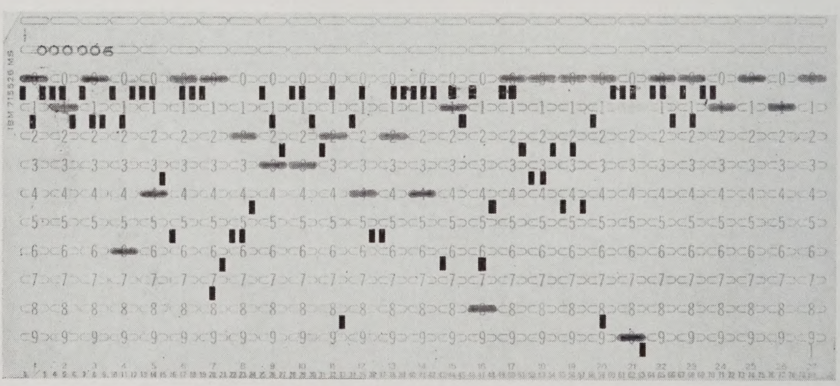
Fifteen plantations in Winnebago and Ogle counties (Fig. 8) were selected for intensive study. One contained 3 acres, the rest 1 acre each. Various conditions of age, composition, stand density, and soil were represented among them.

Circular plots of one-tenth acre were adopted as the sampling units because the size fitted conveniently into the small plantations. Sample units were laid out systematically on diagrams of each plantation and assigned numbers. The sample plots for each plantation were then selected by using a table of numbers.

Data collected concerning each individual tree, as well as information applicable to an entire plantation, were recorded in the field on mark-sense cards (Fig. 9). Later this information was transferred to cards for machine processing.

In 1956, 81 cross sections of trunks were cut from 30 heavily infested Scotch pines in order to determine the incidence of infestation by years throughout the life of each tree and the influence of injury upon growth. These sections were obtained from trees on plantations 2, 6, 10, 13, and 14 (Fig. 8). The sections were allowed to dry and were then sanded smooth with a belt sander so that the rings could be examined and the number of attacks determined by years.

Approximate location of the 15 plantations sampled in the Zimmerman pine moth investigation. (Fig. 8)



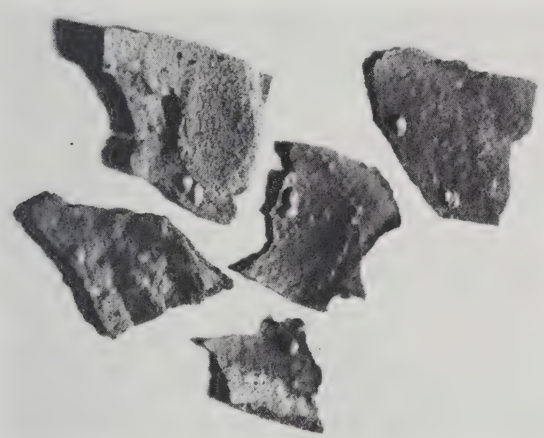
A mark-sense card of the type used for recording data on plots. (Fig. 9)

BIOLOGY

Description of Life Stages and Seasonal History

Since taxonomic descriptions of the larvae, pupae, and adults of the Zimmerman pine moth have been published by Grote (12) and Heinrich (14), only some of the more conspicuous features useful to the forester or entomologist for tentative identification will be given here. Positive identification should be made by a competent specialist.

The eggs (Fig. 10) have not previously been described. They are typically ovoid and approximately 1/32 inch long, slightly flattened on the basal surface, and lightly patterned on the upper surface. Creamy white upon oviposition, they gradually become darker as the embryo develops. At the time of hatching, the color is a light reddish to dark brown.



Eggs of the Zimmerman pine moth on the underneath edges of Scotch pine bark. (Twice natural size.) (Fig. 10)

The larvae (Fig. 11) are approximately 1/16 inch long upon hatching. At first they are a light reddish brown but become darker with age. The head is light brown, and the mandibles are black. After the first instar, the body color is variable, ranging from light gray through brownish or reddish yellow to greenish at full growth. The body is naked except for single bristles arising from dark spots on the lateral and dorsal surfaces. The

Nearly mature larvae of the Zimmerman pine moth. (Slightly more than natural size.) (Fig. 11)

larvae possess four pairs of abdominal prolegs and a pair of anal claspers. When full grown the larvae are about one inch in length.

The pupae (Fig. 12) are light brown when newly formed but become progressively darker and at last almost black because of the development of pigmentation on the wings and body of the enclosed moth. The pupae are unarmed, taper gradually toward the posterior end, and are between ½ and ¾ inch long.

Pupae of the Zimmerman pine moth. (Twice natural size.) (Fig. 12)

The adult moth (Fig. 13) is ½ to ⅝ inch long with a wing expanse of 1 to 1½ inches. Males and females are approximately the same size and color, ranging from light to dark gray, sometimes with a reddish cast. The front wings are gray with red markings and with alternating zigzag light and dark lines. The hind wings are pale yellow, the color deepening toward the terminal fringe.

Adults emerge during the latter half of July and the first half of August. Maximum emergence at Champaign, Illinois, occurred during the first week of August, but the peak in northern Illinois was approximately 7 to 8 days later. Most of the moths in a locality emerge within a period of about a week, although a few may be earlier and a few later. The earliest observation of an adult in Illinois was on July 5; the latest, August 15.

(Left) copulating pair of the Zimmerman pine moth. (Right) adult with wings spread. (About natural size.) (Fig. 13)

The adults are nocturnal and hence are seldom seen. For this reason observations on adult activities were limited to caged specimens. Mating occurred within a day following emergence, and oviposition followed within 2 or 3 days. Although the moths are nocturnal under natural conditions, in cages oviposition took place during both day and night. Oviposition extended over a 3-day period. Males in confinement lived 2 to 3 days following copulation, whereas females remained alive up to a maximum of 17 days under the same conditions. Adult longevity under natural conditions is not known, but it seems that it should be at least as long as that observed in the laboratory.

The eggs are inconspicuous and difficult to find. They are laid, for the most part, during the month of August. The writer has found them on the edges of sapsucker peck holes, on resin masses, and on terminal buds of Scotch pine (*Pinus sylvestris* Linnaeus). Craighead (8) states that they are often laid at the edges of wounds caused by previous attack. Shenefelt and Benjamin (26) report that eggs are laid on the bark or on branch tips in late summer.

Eggs under open-air laboratory conditions hatched in 8 to 10 days. Observations during 1958 under natural conditions indicate a similar incubation period.

Larvae upon hatching are extremely small and are difficult to observe with the naked eye. They feed and move over the bark immediately after emergence. During the late summer and fall, those attacking leaders feed on the outside at the base of terminal buds, and those attacking the trunk feed on the outer bark. During the winter inactive larvae are to be found at the base of terminal buds or under bark flakes where they are concealed under a hibernaculum-like tent of resin and bark frass. Major external feeding, tunneling of the leaders (Fig. 14), and feeding and damage in the phloem and cambium region of the trunk (Fig. 14) occur in the following spring and summer. Consequently, drooping or dead leaders and resin mass accumulations along the trunk do not appear as evidence of infestation until late spring.

In Illinois larvae reach maturity during the first to third week in July. During the last larval stage, they become sluggish and spin a white silken cocoon in a previously prepared enlargement in a tunnel or in a resin mass. There pupation takes place. The pupae are always oriented so that their anterior end is toward an exit. The length of the pupal period is variable. Brunner (3) states that in Montana it is 29 days. However, in the open-air laboratory, it required only 15 to 16 days due, presumably, to warmer conditions than those under which Brunner's observations were made.

Shortly after emergence, the adults copulate; eggs are laid; and a new generation of the Zimmerman pine moth is exposed to all of the adversities of the external environment, one year having elapsed since the parents of this new generation hatched from their eggs as minute larvae.

(Left) red pine leader tunneled by a Zimmerman pine moth larva.
(Right) peeled section of Scotch pine trunk showing areas damaged by feeding of Zimmerman pine moth larvae.
(Fig. 14)

Reproduction

The act of mating has been observed only in the open-air laboratory. It has always taken place between 10:30 p.m. and 4:30 a.m. Moths were in the resting position, facing in opposite directions during the process (Fig. 13).

Separation was not effected in most instances when pairs were carefully urged into glass jars for oviposition studies. Pairs continued to copulate for as long as 2½ hours, but no maximum or minimum time limits were established. Neither is it known if mating occurs more than once.

Oviposition has been observed only in confinement. Moths failed to oviposit in the large cage enclosing small pine trees, apparently due to their continuous effort to escape. Copulating pairs were then confined in screen-wire covered glass jars. Under these conditions in 1953, two females laid eggs. This is the first time the oviposition habits of this insect have been recorded.

The first female observed laying eggs was copulating at 3:30 a.m. on August 11, 1953. She was placed, along with the male, in a quart jar containing a piece of Scotch pine bark. At 9 p.m. on August 16, the first egg was laid on the side of the jar. Between then and 8 a.m. on August 19, a total of 42 eggs was deposited, 40 on the sides of the jar and 2 on the bark. Oviposition continued throughout 59 hours with no evidence of photoperiodism. As the eggs developed, they changed from a light cream color, through various shades of red, to a final light brown. These color changes began within approximately 24 hours. Hatching began at 8:30 p.m. on August 26 and was completed by 8 a.m. the following morning.

The second moth mated on August 18 and laid 24 eggs between August 20 and 22. On September 1 they all hatched after passing through the color changes described above.

Additional information on the egg-laying habits of this species was obtained from 14 mated pairs confined separately in screen-wire cages attached to pine trunks. These cages were all the same size and the enclosed bark was similar, with some smooth areas and some rough areas. Artificial wounds were created where none existed. Wounds with free-flowing resin were usually avoided by the females. Most of the eggs were laid either under bark scales or on the screen. In only two cages, 1 and 14, were appreciable numbers of eggs laid on the bark surface. These were deposited on rough bark adjacent to a branch stub (Table 1). This appeared to be attractive only because of the rough and depressed condition.

Eggs were deposited singly or in pairs except in one instance when 13 eggs were laid together in a mass on the screen wire of the cage. Field observations also indicate that eggs are laid, as a rule, on rough bark or under bark scales, either singly or in pairs.

The sex factor for the Zimmerman pine moth, as determined from examination of 123 adult moths reared from field collections in 1958, was 0.545. Of the 123 adults, 67 were females and 56 were males.

Eggs laid, plus those remaining in the ovaries (Table 1) for the 14 females upon which records were obtained, ranged from 11 to 65. One gravid female contained 82 eggs in the ovaries.

This insect produces one generation per year and one embryo per egg.

Since the greatest number of eggs observed in gravid females was 82, this number is tentatively assumed to represent the maximum fecundity. Upon this assumption the reproductive potential for this species, expressed for a single insect, is $1 \times (0.545 \times 82)$ or 44.69.

Table 1. — Fecundity of the Moth

Female by number	Number of eggs laid: On screen	On bark	Under bark	Total	Number of eggs retained in ovaries	Number of eggs, total
1	9	15	17	41	8	49
2	22	1	26	49	1	50
3	13	0	0	13	0	13
4	5	0	2	7	4	11
5	2	3	2	7	28	35
6	0	0	0	0	25	25
7	0	0	0	0	39	39
8	1	2	6	9	10	19
9	2	2	7	11	28	39
10	0	0	0	0	50	50
11	0	1	0	1	30	31
12	19	0	19	38	0	38
13	24	4	2	30	27	57
14	25	10	30	65	0	65
Total	122	38	111	271	250	521
Average	...	...	...	19.4	17.1	...

Hosts

In Illinois the Zimmerman pine moth is known to attack Scotch pine (*Pinus sylvestris* Linnaeus), Corsican pine (*Pinus nigra poiretiana* Ant.), Japanese red pine (*Pinus densiflora* Sieb. and Zucc.) red pine (*Pinus resinosa* Aiton), western yellow pine (*Pinus ponderosa* Dougl.), lodgepole pine (*Pinus contorta* Dougl.), eastern white pine (*Pinus strobus* Linnaeus), jack pine (*Pinus banksiana* Lamb.), Austrian pine (*Pinus nigra* Arnold), and mugo pine (*Pinus mugo* Turra). It has not been observed to attack Douglas fir (*Pseudotsuga taxifolia* (Poir) Britt.), as reported by Brunner (3) for western United States, but appears capable of attacking all members of the genus *Pinus.*

From variation in intensity and severity of infestations, there is a strong indication that the moth prefers certain hosts. Scotch, Corsican, and Japanese red pine appear to be particularly attractive. The percentages of infestation in seven different pine species at Sinnissippi Forest in 1951 are presented in Table 2.

It will later be shown that density of stand influences the susceptibility of trees to attack and injury by the Zimmerman pine moth. Therefore the influence of this factor upon the results summarized in Table 2 is a question that might logically be raised. There seems to be little or no correlation between the number of trees per acre and the number of trees infested in each block (Table 2). Therefore it seems

Table 2. — Trees Infested; Experimental Plantation; Sinnissippi Forest; Oregon, Illinois; Summer, 1951

Hosts	Trees per acre	Infested	Free of infestation	Infestation
	no.	*no.*	*no.*	*perct.*
Scotch pine *(Pinus sylvestris)*	655	513	142	78.3
Corsican pine *(Pinus nigra poiretiana)*	713	614	99	86.1
Japanese red pine *(Pinus densiflora)*	418	263	155	62.9
Red pine *(Pinus resinosa)*	1,073	444	629	41.4
Ponderosa pine *(Pinus ponderosa)*	600	165	435	27.5
Lodgepole pine *(Pinus contorta)*	416	76	340	18.3
Jack pine *(Pinus banksiana)*	1,035	61	974	5.9

justifiable to assume that the differences between species are sufficient to mask any influences of density variations and that the percentages of infestation actually indicate the relative preference of the moth for the different species of pine growing together in these plantations.

Infestation percentages, by species, for the plantations sampled after 1951 (Table 3) show similar trends of susceptibility. Scotch pine generally appears to be subject to somewhat heavier infestation than other species. However, a high level of infestation appears possible for most pines under conditions favorable to the insect. The presence of Scotch pine, in mixture with other species, does not seem to be necessary for a high moth population, as has been suggested.

Parasites and Predators

Observations on the parasite and predator relationships were made both in the field and in the laboratory.

Larval parasites of the Zimmerman pine moth collected and identified were: Eulophidae — *Melittobia chalybii* (Ashm.); *Hyssopus rhyacioniae* (Gah.); *Elachertus pini* (Gah.); Ichneumonidae, *Calliephialtes comstocki* (Cress.); Eurytomidae, *Eurytoma pini* Bugbee.

The percentage of parasitism observed in larvae and pupae collected in the field was not sufficient to suggest that parasites alone can effectively control the moth. Seldom were more than 1 to 5 percent of the larvae and pupae parasitized. The predominant parasite observed was *Hyssopus rhyacioniae* (Gah.).

Predation was observed principally under open-air laboratory conditions. There unidentified web-spinning spiders caught and preyed heavily upon adult moths. It would appear that predation by both web-spinning and nonweb-spinning spiders might be an important mortality factor. However, field observation has not confirmed this.

Table 3. — Infestation by Species and Plantation; 15 Plots on 15 Plantations

Species and plantation	Trees on sample plot	Total composition	Attack	Attack by position: Trunk		Whorls		Leaders	
				Number	Percent	Number	Percent	Number	Percent
	no.	*perct.*	*perct.*						
Less than 22 years old									
Plantation 4									
Red pine	30	28.8	0	0	0	0	0	0	0
Jack pine	43	41.3	9.3	0	0	1	25.0	3	75.0
White pine	31	29.8	0	0	0	0	0	0	0
Plantation 5, red pine	97	100.0	39.2	28	43.1	31	47.7	6	9.2
Plantation 8, jack pine	114	100.0	15.8	0	0	0	0	18	100.0
Plantation 9									
Red pine	45	43.3	13.3	0	0	6	100.0	0	0
Jack pine	18	17.3	38.9	0	0	8	100.0	0	0
White pine	14	13.5	0	0	0	0	0	0	0
Ponderosa pine	27	26.0	18.5	0	0	5	100.0	0	0
Plantation 10, Scotch pine	74	100.0	32.4	0	0	23	95.8	1	4.2
Plantation 13, Scotch pine	74	100.0	44.6	2	5.9	32	94.1	0	0
Plantation 15, jack pine	110	100.0	7.3	0	0	8	100.0	0	0
Total	..	....	....	30	....	114	....	28	....
Distribution, percent	..	....	....	..	17.4	..	66.3	..	16.3
More than 22 years old									
Plantation 1, Scotch pine	39	100.0	41.0	10	40.0	14	56.0	1	4.0
Plantation 2									
Scotch pine	17	51.5	52.9	1	10.0	9	90.0	0	0
Jack pine	8	24.2	50.0	1	16.6	4	66.7	1	16.7
White pine	8	24.2	50.0	1	25.0	3	75.0	0	0
Plantation 3, Scotch pine	82	100.0	11.0	0	0	9	100.0	0	0
Plantation 6									
Scotch pine	16	44.4	62.5	0	0	10	100.0	0	0
White pine	20	55.6	0	0	0	0	0	0	0
Plantation 7									
Scotch pine	15	34.9	40.0	0	0	6	100.0	0	0
Jack pine	28	65.1	53.6	3	17.6	14	82.4	0	0
Plantation 11									
Jack pine	3	23.1	66.7	0	0	2	100.0	0	0
White pine	10	76.9	80.0	1	11.1	8	88.9	0	0
Plantation 12									
Jack pine	32	52.5	0	0	0	0	0	0	0
White pine	28	45.9	0	0	0	0	0	0	0
Ponderosa pine	1	1.6	100.0	0	0	1	100.0	0	0
Plantation 14, Scotch pine	37	100.0	70.3	0	0	23	95.8	1	4.2
Total	..	....	....	17	....	103	....	3	....
Distribution, percent	..	....	....	..	13.8	..	83.7	..	2.8
Total, all plots	..	....	....	47	....	217	....	31	....
Distribution, percent, all plantations	..	....	....	..	15.9	..	73.6	..	10.5

Possible insect predators present on infested pines were ants, larvae of lace wings, and cockroaches; but the importance of their predatory activities has not been established.

According to Brunner (3) woodpeckers are an efficient factor of environmental resistance to the moth in stag-headed ponderosa pine in the northern Rocky Mountains. The yellow-bellied sapsucker, *Sphyrapicus varius varius* (Linneaus), frequently has been suggested to the author as a possible predator. However, it feeds mainly on sap, and as larvae have often been found uninjured in bark recently worked on by the birds, sapsuckers do not appear to be an important resistance factor in Illinois.

Dispersal

Dispersal of the moth in Illinois has resulted from transportation of infested ornamental pines and from moth flight. Spread by means of forest planting stock is ordinarily impossible, as the trees are usually too small to be infested.

The nuclei from which spread has occurred, largely by moth flight, have been infested ornamentals in parks, cemeteries, windbreaks, ornamental nurseries, and infested plantations. The insect may be expected to appear in plantations now free of infestation through movement of the moths from near-by infested plantations or from infested ornamentals.

DAMAGE

A study of damage caused by this moth in Illinois has been confined to planted pine trees ranging from 3 to 40 feet in height and from 1½ to 10 inches in diameter at breast height. Larger trees are subject to infestation and damage but were not included in this study.

The character of the damage is dependent upon the location, severity, and duration of the attack on the tree. Infestation may occur either at the extremities of the branches or along the trunk at branch whorls or between whorls.

Infestation may be severe enough to kill trees or, if lighter, may only retard height growth or affect adversely the form of the trunk. Doane (9) states that in trees of sawlog size infestation of the trunk may greatly reduce their value for lumber. Ornamentals and trees intended for Christmas trees may be rendered worthless.

The same amount of infestation does not cause the same amount of damage in trees of different species. Table 4 gives the percentage of trees examined in this study which were broken or of poor form as a result of infestation. Damage as indicated in the table was much more severe for Scotch pine than for other species.

Tip

Larvae may damage either the base of the terminal growth of the main leader or the base of the lateral branches. Lateral branches may be girdled at their base and eventually fall from the tree. The terminal leader may likewise be girdled and killed. In other instances a larva may tunnel up into or down into a central leader (Fig. 14). Either may reduce height growth, the amount of reduction depending upon the location and severity of attack. The loss will equal the difference

Table 4. — Effect of Injury on Trees by Species and Plantation; 15 Plots on 15 Plantations

Species and plantation	Trees per acre in open and dense plantings	Trees per plot	Attack	Broken or poorly formed trees	Stand infested
	no.	*no.*	*no.*	*perct.*	*perct.*
Less than 22 years old					
	open				
Plantation 10, Scotch pine. . . .	740	74	24	66.7	32.4
Plantation 13, Scotch pine. . . .	740	74	33	75.8	44.6
Plantation 5, red pine.	970	97	38	23.7	39.2
Plantation 4.	1,040	..	..	....	....
White pine.	....	31	0	0	....
Red pine.	....	30	0	0	....
Jack pine.	....	43	4	100.0	....
Percent stand infested, Plantation 4.	....	..	..	....	8.4
	dense				
Plantation 9.	1,040	..	..	....	....
White pine.	....	14	0	0	....
Red pine.	....	45	6	83.3	....
Jack pine.	....	18	7	0	....
Ponderosa pine.	....	27	5	40.0	....
Percent stand infested, Plantation 9.	....	..	..	....	17.3
Plantation 15, jack pine.	1,100	110	8	12.5	7.3
Plantation 8, jack pine.	1,140	114	18	100.0	15.8
More than 22 years old					
	open				
Plantation 11.	130	..	..	....	....
White pine.	....	10	8	0	....
Jack pine.	....	3	2	0	....
Percent stand infested, Plantation 11.	....	..	..	....	76.9
Plantation 2.	330	..	..	....	....
Scotch pine.	....	17	9	44.4	....
White pine.	....	8	4	0	....
Jack pine.	....	8	4	0	....
Percent stand infested, Plantation 2.	....	..	..	....	51.5
Plantation 6.	360	..	..	....	....
Scotch pine.	....	16	10	80.0	....
White pine.	....	20	0	0	....
Percent stand infested, Plantation 2.	....	..	..	....	27.8
Plantation 14, Scotch pine. . . .	370	37	26	64.0	70.3
Plantation 1, Scotch pine.	390	39	16	35.3	41.0
Plantation 7.	430	..	..	....	....
Scotch pine.	....	15	6	33.3	....
Jack pine.	....	28	15	20.0	....
Percent stand infested, Plantation 7.	....	..	..	....	48.8

Table 4. — Concluded

Species and plantation	Trees per acre in open and dense plantings	Trees per plot	Attack	Broken or poorly formed trees	Stand infested
	no.	*no.*	*no.*	*perct.*	*perct.*
	dense				
Plantation 12	610	..	..	....	....
White pine	....	28	0	0	....
Jack pine	....	32	0	0	....
Ponderosa pine	....	1	1	0	....
Percent stand infested, Plantation 12	....	..	..	....	1.6
Plantation 3, Scotch pine	820	82	9	66.7	11.0

between the length of the main stem killed and the length of the lateral that takes its place. If, however, two side branches assume the terminal position, forked trees will result (Fig. 15).

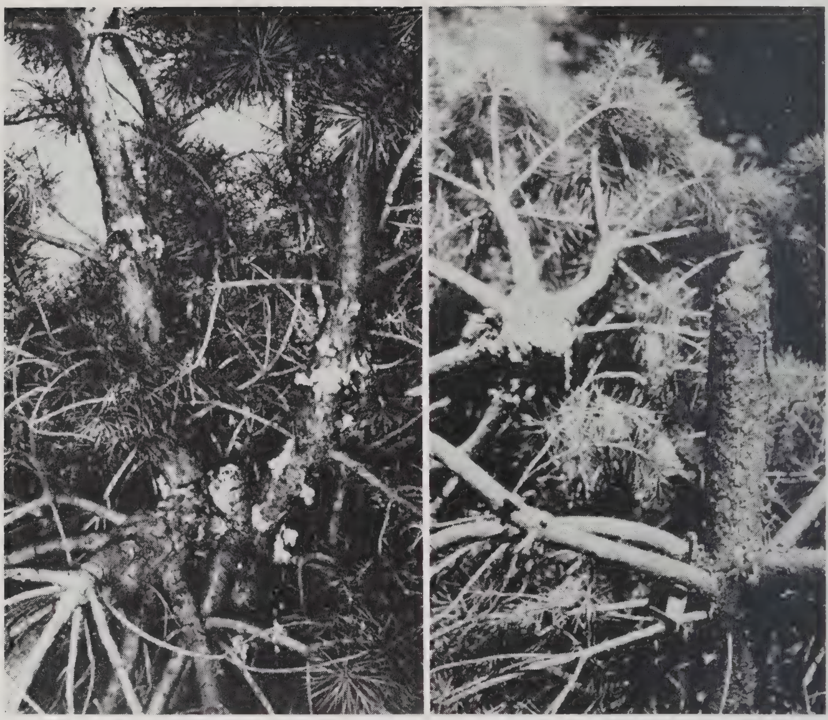
Infestation at the last whorl of the side branches is rather rare. When such attacks do occur, they follow the same general pattern as those at the top of trees; but since the trunk is not affected, no injury to the quality of wood will result from this injury to the branches.

Trunk

The larvae may attack the base of the lateral branches where they join the trunk, successively girdling branches at a given whorl until all may be weakened and break off. When all branches at a whorl are killed, the main trunk may be so weakened that it breaks at the point of injury (Fig. 15). Trees are seldom infested below a point 2 feet above the ground.

Infestation may extend along the trunk between branch whorls, tunnels running either vertically or horizontally. When they extend horizontally, the trunk is sometimes completely girdled, resulting in death of the tree above the point of infestation.

The presence of larvae in the trunk is indicated by exudation of resin mixed with the larval frass (Fig. 16). Shiny and sticky resin masses are indicative of active infestation, whereas the hardened and darker colored ones are from previous years. Infestation above the top whorl of branches does not ordinarily produce resin masses.



(Left) forked Scotch pine (*Pinus sylvestris* L.), the result of elimination of the main trunk by repeated attacks of Zimmerman pine moth larvae. (Right) Scotch pine rendered worthless by breakage from snow and wind after heavy Zimmerman pine moth infestation. (Fig. 15)

Vertical Distribution and Cardinal Direction of Attacks

Trunk infestations were found as low as 1 foot above the ground and as high as 25 feet. Percentage distribution of attack points observed in 15 plantations are shown by 5-foot height intervals in Table 5. These data suggest that the zone especially favored by this insect is between 6 and 15 feet.

Two anomalies from the general trend in Table 5 are explainable. Plantation 8 was a 7-year-old jack pine planting that, because of its youth, was susceptible to leader attack only. Plantation 12 was a dense 27-year-old stand containing white, jack, and ponderosa pine, which had not been attractive to the moth due to its density. In the one-tenth-acre plot, only one attack was found on a single ponderosa pine.

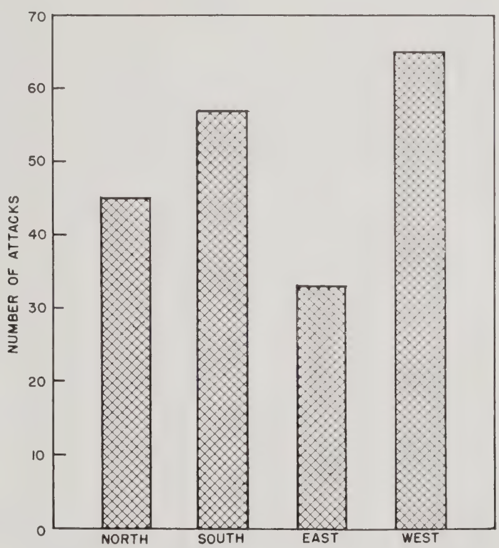
In order to determine whether one side of a tree was more likely

Trunk section of a Scotch pine (*Pinus sylvestris* L.), with huge resin masses, resulting from Zimmerman pine moth infestation. (Fig. 16)

to be attacked than another, the location of external evidence of infestation was recorded according to the cardinal directions. These data are summarized in Table 6. No directional preference is indicated. This was to be expected because the long crowns in most of the plantations shaded the trunks, creating similar conditions on all sides.

When attack points on the trunks are considered separately, however, a directional preference becomes apparent. A record of individual attacks observed on cross sections from 30 trees felled during 1956 is presented in Fig. 17. This indicates that attacks on the trunk are somewhat more likely to occur on the sides exposed to intense radiation than on the north or east sides. Since these trees had been heavily infested for several years previous to felling, they had more poorly developed crowns than they otherwise would have had. For this reason greater differences in the intensity of radiation on the trunk were to be expected, resulting in a more pronounced effect upon the insects' distribution.

The attacks on the trunk cross sections were recorded in a manner to eliminate bias. This was accomplished by recording each attack which occurred between cardinal directions as one infestation for each.



Cardinal direction of moth attacks on cross section of 30 Scotch pines cut in 1956. (Fig. 17)

Table 5. — Vertical Distribution of Infestation; 15 Plots on 15 Plantations

Plantations by number	Trees per plot	Average height, feet	Percent of attacks by 5-foot height intervals: Under 5 feet	6 to 10 feet	11 to 15 feet	16 to 20 feet	21 to 25 feet
			Less than 22 years old				
4	104	11.7	12.5	25.0	62.5	0	0
5	97	23.7	35.5	17.1	25.0	7.8	14.4
8	114	8.0	0	100.0	0	0	0
9	106	22.0	11.1	58.3	25.0	5.5	0
10	74	29.0	0	8.3	47.9	35.4	8.3
13	74	24.0	0	56.0	34.8	9.0	0
15	110	29.0	37.5	25.0	12.5	25.0	0
			More than 22 years old				
1	39	29.0	9.3	37.5	31.2	21.8	0
2	33	29.2	17.6	41.2	26.8	14.7	0
3	82	38.8	0	27.7	33.3	16.6	22.2
6	36	24.5	10.0	40.0	35.0	10.0	5.0
7	43	31.0	19.0	59.5	9.5	11.9	0
11	13	32.0	30.0	25.0	10.0	30.0	0
12	61	31.0	0	0	100.0[a]	0	0
14	37	22.0	34.6	53.8	11.5		

[a] A single infestation.

Table 6. — Influence of Direction on Frequency of Attack;[a] 1956

Plantations by number	Density of stand	Total number of attacks	North: Number	North: Percent	South: Number	South: Percent	East: Number	East: Percent	West: Number	West: Percent
			Less than 22 years old							
5	970	48	13	27.1	17	35.4	8	16.6	10	20.9
8	1,140	49	10	20.4	13	26.5	14	28.6	12	24.5
9	1,060	36	7	19.4	10	27.8	10	27.8	9	25.0
10	740	84	20	23.8	21	25.0	22	26.2	21	25.0
13	740	112	26	23.2	30	26.8	29	25.9	27	24.1
15	1,100	14	1	7.1	5	35.7	4	28.6	4	28.6
Total	...	343	77	....	96	....	87	....	83	....
Percent	...	..	..	22.4	...	28.0	...	25.4	...	24.2
			More than 22 years old							
6	360	34	10	29.3	8	23.5	7	20.6	9	26.6
7	430	56	19	33.9	11	19.6	14	25.1	12	21.4
11	130	20	5	20.0	6	30.0	5	20.0	4	25.0
12	610	2	1	50.0	1	50.0	0	0	0	0
14	370	82	21	25.6	20	24.4	21	25.6	20	24.4
Total	...	194	56	....	46	....	47	....	45	....
Percent	...	...	...	28.9	...	23.7	...	24.2	...	23.2
Total, all plantations	...	537	133	....	142	....	134	....	128	....
Percent, all plantations	...	...	...	24.8	...	26.4	...	25.0	...	23.8

[a] Attacks on plantations 1 through 4 were not tallied by cardinal directions.

RELATIONSHIP OF TREE AND STAND CHARACTERISTICS AND CONDITIONS TO INFESTATION

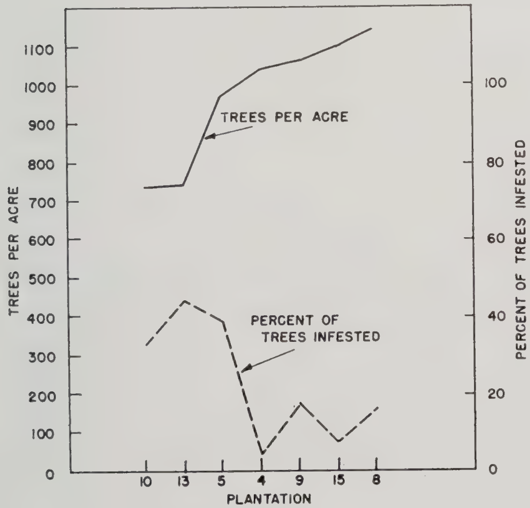
Spacing

Stand density appeared closely associated with severity of infestation. The original spacing in all plantations studied was 6 × 6 feet; but mortality was heavy in some plantations, thus producing a variety of densities in the plot series. When percentage of infestation is plotted against plantation density (Figs. 18 and 19), a downward trend in infestation is correlated with increasing stand density. The departures from this trend are explainable.

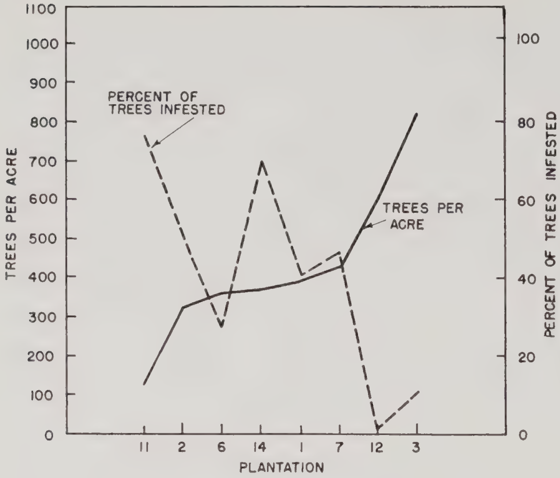
Density did not appear as closely related to the amount of infestation in young plantations, where only leaders were attacked, as in older plantations where trunk infestation predominated. This indicates that light or temperature is important in determining the amount of infestation.

The high percentage of open-grown ornamental pines infested in areas of the state where the moth is present further suggests that open-stand conditions may contribute to the incidence of attack. In this study a special effort was made to evaluate this factor.

In 1958 a number of Scotch pines were examined to provide additional evidence of the effect of density on infestation. Thirty-nine widely spaced ornamental trees with large crowns, 100 closely spaced shelterbelt trees, 246 trees on the outer edge of sampled plantations, and 100 trees within the interiors of those same plantations were



Stand density and percentage of trees infested for plantations less than 22 years old. (Fig. 18)



Stand density and percentage of trees infested for plantations more than 22 years old. (Fig. 19)

inspected for evidence of infestation. The two plantations sampled were selected so that they would be as nearly alike as possible in all respects except stand density.

Edge trees were examined in sequence. Interior trees were selected systematically, starting three trees in from one corner of each plantation. Trees in alternate rows were examined until a total of 100 interior trees had been tallied.

The results (Table 7) emphasize the close relationship between stand density and the amount of infestation. The percentage of infestation of the shelterbelt trees was lower than might have been expected because approximately 20 percent of the most heavily infested had previously been removed. Furthermore, a portion of the shelterbelt received shade from adjacent hardwood trees to the south. Of the 100 trees examined in the shelterbelt, 46 received some shade from these trees, whereas only 54 were completely unshaded. Only five of the 46 were attacked by the moth, whereas 16 of the 54 unshaded trees were infested. The influence of the hardwood shade certainly appeared to be responsible for this difference in infestation.

Percentage of infestation in border trees, as compared with those in the interior of plantations, show further evidence of the apparent relationship between solar radiation and infestation. Infestation of marginal trees was higher than that of interior trees. Infestation percentages for north and east edges were lower than those for south and west edges. All these observations point strongly to a close relationship between the intensity of infestation and exposure to light.

Table 7. — Infestation of Scotch Pine, 1958

Item	Number of trees	Trees infested		Trees uninfested	
		Number	Percent	Number	Percent
Ornamental trees, individual	39	37	94.9	2	5.1
Two-row shelterbelt, 4-to 5-foot spacings	100	21	21.0	79	79.0
Open plantation					
Interior trees	100	41	41.0	59	59.0
Edge trees	100	52	52.0	48	48.0
Edge trees on:					
North	26	7	26.9	19	73.1
South	23	19	82.6	4	17.4
East	25	8	32.0	17	68.0
West	26	18	69.2	8	30.8
Dense plantation					
Interior trees	100	14	14.0	86	86.0
Edge trees	146	31	21.2	115	78.8
Edge trees on:					
North	26	4	15.4	22	84.6
South	27	7	25.9	20	74.1
East	50	7	14.0	43	86.0
West	43	13	30.2	30	69.8

Pruning

Pruning trees, particularly the removal of live branches, sometimes appeared to increase the incidence of moth infestation. This seems reasonable in view of reports by Kellicott (19) and Craighead (8) that the moth frequently attacks at points of injury.

The limited information on the influence of pruning collected in this study seems inconclusive. Trees had been pruned on only five of the plantations sampled. On these, the trees had either all or nearly all been pruned. Therefore, the same number of pruned and unpruned branches had not been subjected to equal chances of being attacked under similar conditions. Hence the results were necessarily biased and, therefore, provide an unreliable basis for formulating pruning practice recommendations.

However, the percentage of infestation in plantation 5 does suggest that pruning may increase the level of infestation. In this red pine plantation, live branches had been pruned each year since 1950 for a Christmas greens study. Infestation in 1956 was 39.2 percent. This is unusually high for red pine, particularly for a plantation with a stand density of 970 trees per acre. Infestations in other red pine plantations at Sinnissippi Forest of the same age that had not been pruned and that were growing under similar conditions averaged 3 to 5 percent.

Subsequent studies can readily determine the preference of the

Zimmerman pine moth for pruning wounds as compared with unpruned branch bases. This can be accomplished by pruning 100 or more branches on trees within a stand susceptible to attack, leaving as controls the same number of unpruned branches on trees in the same stand, growing under similar conditions. This pruning should be done in the spring or early summer prior to oviposition. Infestation percentages should be checked the following spring or summer.

Invasion of New Plantations

Little evidence could be obtained concerning the time required for moths to infest a plantation. Plantation 8 was the only one studied which was not within a few hundred feet or immediately adjacent to a source of infestation. This plantation was approximately 2 miles from known infested trees. It was not attacked until the seventh year after establishment.

Another plantation at Monticello, Illinois, in Piatt county, although not studied intensively, contributes some information on invasion rate. This plantation is ½ mile from heavily infested Scotch pines. It escaped attack until the eighth year after planting. In both instances, moth flight was against prevailing winds, a condition that might have delayed invasion.

From the above observations, we may tentatively conclude that if a source of infestation is no nearer a newly established plantation than 5 to 10 miles, attack might be delayed until the crowns have closed. After that injury to the trees would be slight.

Characteristics and Conditions not Correlated

Neither the source of the planting stock nor the mixture of various species of pines in a single plantation had discernible influence on moth infestation. Neither did the character of ground vegetation, litter depth, aspect or slope seem to affect the degree of infestation. Soil quality had no apparent effect, although casual inspection might suggest that it did because on the poorer soils partial mortality of the planted trees frequently produced scattered stands which were heavily attacked (Table 8). However, in dense stands which became established on similar poor soils, the infestations were always low.

Diameter and height differences within the range of high susceptibility had no influence on the degree of infestation. After the tree reached a diameter at breast height of 2½ to 3 inches, the trunks were attacked, thus adding to the severity of infestation. Later when the trees reached a height of 20 feet or more, infestation decreased.

Larvae rarely reach maturity in the trunk until the bark on the trunk reaches a thickness of 0.15 inch. Many which enter the thin

Table 8. — Soil Descriptions of Plantations[a]

Plantation by number	Soil type[b]	Age of stand, years	Trees per acre	Infestation, percent
1	Ritchey sandy loam	24	390	41.0
2	Ritchey sandy loam	27	330	51.5
3	Huntsville loam	27	740	11.0
5	Carmi sandy loam	20	970	39.2
6	Alvin sandy loam	25	360	27.8
7	Ritchey sandy loam	28	430	48.8
9	Onarga sandy loam	21	1060	17.2
10	Bloomfield fine sand	20	740	32.4
11	Pecatonica silt loam	26	130	76.9
12	Unity sandy loam	27	610	1.6
13	Onarga sandy loam	20	740	44.8
14	Rodman gravelly loam	22	370	70.3
15	Carmi sandy loam	18	1100	7.3

[a] Plantations 4 and 8 are not included in this table because they were too young to have been very much infested.
[b] The soil types are tentative since soil correlation and reclassification in the area is still in progress.

phloem succumb. These attack points are sometimes indicated by small masses of hardened resin in which the larvae are embedded. Observations have not confirmed a similar high mortality rate in the thin bark at the base of terminals, although this might logically be expected. The fact that girdling at these basal points occurs more frequently than successful tunneling of terminals suggests considerable mortality. Rarely have more than 10 percent of the attacked terminals contained mature larvae or pupae when examined late in July.

After the bark reaches the necessary thickness to permit attack, such as 0.15 inch, no increase of infestation could be demonstrated as the bark became thicker.

POPULATION TREND IN ILLINOIS

Estimate From Resin Masses

Infestation by the Zimmerman pine moth is indicated by accumulations of resin masses on the trunk. Those of current seasons are characterized by shiny, sticky resin masses. The resin masses over older attacks are hard and darkened.

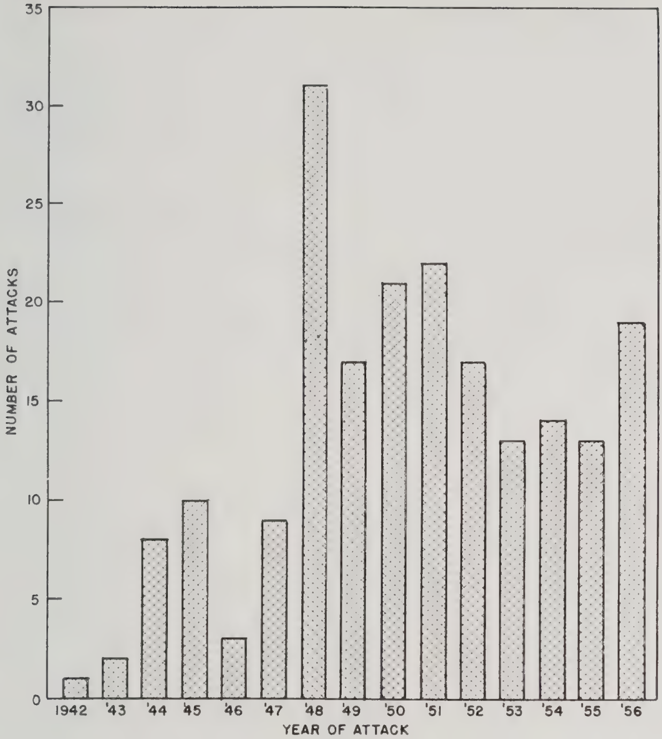
A systematic count of fresh resin masses each year on a definite unit provides a means of comparing relative moth abundance from year to year. This procedure does not show the absolute population numbers, since one or several larva may work beneath the same mass, pushing frass and resin from a common opening.

Nevertheless, counts of new as compared with old resin masses is a practical method of determining the approximate rate of population increase from one year to the next within a plantation. The past population trends cannot be estimated from resin masses because the age of the old masses cannot be recognized from external appearance. Accurate dating of attacks can only be accomplished from study of the annual rings.

Estimate From Cross Sections

Cross sections taken from the trunks of heavily infested trees at points of attack are the most practicable way to reconstruct the past population trends of this insect. In order to obtain this information, 81 sections from 30 heavily infested Scotch pines were collected and rings were carefully dated. The number of past attacks was recorded by years. Each attack was easily recognized on the cross sections because feeding of the larvae stimulated resin formation in the adjacent wood impregnating the annual ring laid down the year the tree was injured (Fig. 20). Later the resin which exuded when attacks occurred

Scotch pine trunk cross section showing resin impregnated areas, the result of attack by Zimmerman pine moth larvae. (Fig. 20)



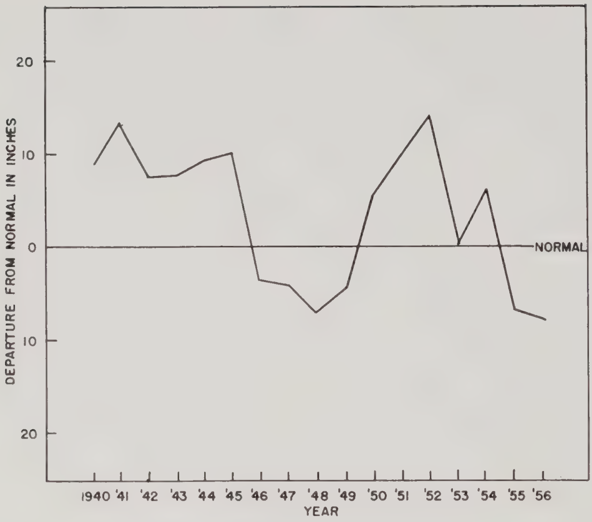
Total number of Zimmerman pine moth attacks on the trunk by years on 30 Scotch pines. (Fig. 21)

became overgrown by callus growth. This callus growth was a helpful aid in recognizing the ring when first injury occurred.

The earliest attack on the trunks of trees in the plantations studied was in 1942. The population level fluctuated thereafter year by year, a definite population peak occurring in 1948 (Fig. 21) and a depression in 1946. The population increase that occurred between 1942 and 1945 was apparently the initial build-up. Thereafter, the changes were almost certainly the result of annual changes in environmental conditions. There is evidence that these fluctuations may have been due to weather.

Relationship of Weather to Population Trends

The trees reached a size suitable for trunk infestation in the early 1940's, but until 1946 annual precipitation (Fig. 22) was considerably above normal in northern Illinois. This period was characterized by a slow population build-up and a sharp decline in 1946. Below-normal precipitation prevailed between 1947 and 1949, during which time the insect increased sharply in numbers. The years 1950 through 1954



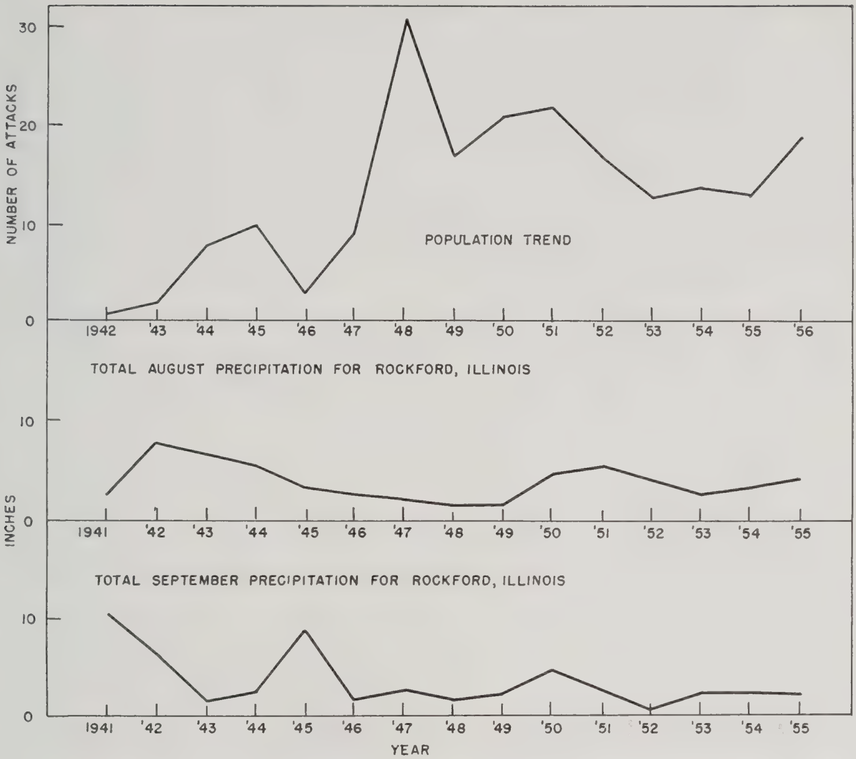
Precipitation departure from normal for Rockford, Illinois. (Fig. 22)

were characterized by higher than normal precipitation, a period when the insect infestation exhibited a downward trend. In 1955 and 1956 the rainfall was relatively low and another increase in numbers of the pine moth occurred.

These observations, although by no means conclusive, suggest strongly that low precipitation may permit the moth population to increase and that high precipitation may be deleterious. Because this insect spends most of its developmental time in the phloem, moisture deficiency that would affect these tissues first would create favorable conditions for the larvae. This harmonizes with effects of dry weather on other phloem borers — the locust borer, *Megacyllene robiniae* (Forst.); the bronze birch borer, *Agrilus anxius* Gory; and others. The adults during the breeding and ovipositing period would be vulnerable to heavy storms. These tentative hypotheses can only be proved by further study in the field and by controlled laboratory experiments that could not be conducted during the present study.

Figure 23 presents the population trends based on the trunk cross-section examination, together with curves for total precipitation by years for the months of August and September. In comparing these curves, it is important to keep in mind that the precipitation of a given year should be reflected in the population level of the following year if a relationship exists between precipitation and population level.

The high precipitation in September 1945 was followed by the



Population trend compared with August and September precipitation, 1941-1955. (Fig. 23)

sharp decline in the population curve for 1946, whereas the low precipitation in the falls of 1946 and 1947 preceded the 1948 population rise. These observations lend support to the hypothesis that precipitation during August and September may be an important factor in the population trends of this species. Precipitation will have a bearing on the survival of planted trees, thus indirectly influencing the pine moth, since planted stands are more likely to remain fully stocked when planted during favorable seasons. Long-range seasonal forecasts may in the future provide information that will guide the increase of planting during such favorable years.

A study of temperatures, particularly the maxima, minima, and monthly means from U.S. Weather Bureau Records showed no correlation with population trends from 1942 through 1956.

Other Limiting Factors

Other factors observed in the study that may in part be responsible for the population reduction deserve mention. These were parasites, predators, and possibly disease. Parasites, as previously indicated, appeared to exert minor influence. Although no measure of predatory pressure has been made, observations suggest that it was not of great magnitude. Larvae were occasionally found dead which displayed symptoms of possible virus or bacterial infection, but culturing of these cases was impractical at the time they were observed. Under some circumstances it may be possible that these factors may exert greater impact upon moth numbers than was apparent during this study. They are therefore worthy of future surveillance.

Future Outlook

This study has been conducted in a locality that is marginal for the northern species of pine, it being close to or beyond the southern limit of their range. Indicative of this is the fact that only white pine was originally native to the area studied. More damage by insects might therefore be expected than would occur well within the range of the host trees. In such a situation one might expect that factors favorable for the insect might exert themselves more forcibly here than in situations better suited to the trees.

The outstanding feature associated with heavy infestations revealed by this study appears to be the amount of exposure toward the south and west to which the trees are subjected. Therefore, every effort should be made to establish fully stocked stands. When this is impossible because of poor sites or other conditions, it is questionable if pines should be encouraged to occupy the land. Such stands as will result will provide nuclei of infestation that will serve as focal points from which the moth may spread into adjacent stands.

Since the Zimmerman pine moth is so well established in northern Illinois, its eradication seems impracticable. This is true not only because of the wide distribution in Illinois of ornamental pines but also because of the moth's occurrence in areas to the north where pines are native. Consequently, outbreaks probably will continue to occur from time to time in Illinois. Suggested preventive practices may be expected to minimize the damage resulting from them.

CONCLUSION AND RECOMMENDATIONS

The results of this study contribute materially to the previous knowledge of the biology and ecology of the Zimmerman pine moth, and consequently add to our understanding of its role as a forest pest. The results should serve not only as a foundation on which to launch subsequent studies of this insect, but properly applied, should lead to reduction of damage through better management of forest plantations. Based on the findings of this study, the following practices are recommended.

Plant pine at 6- × 6-foot spacing or closer.

Avoid planting the especially favored hosts, such as Scotch pine, Corsican pine, and Japanese red pine.

Promptly replant spots where trees have died. After harvesting Christmas trees, fill in open spaces with young trees to maintain full stocking. Where possible, practice intensive management of Christmas tree plantations and clear cut by blocks to avoid open stands.

Where practicable, avoid planting within a half mile of known Zimmerman pine moth infestations.

Do not accept infested pines shipped from nurseries selling either ornamental or forest planting stock.

Choose especially favorable years for planting as soon as it is possible to do so. Long-range weather predictions may soon come into being. When they do, consider these forecasts, particularly those that concern soil moisture or those that may affect plantings on adverse sites. The Zimmerman pine moth population decreases the year following a wet fall.

Remove and destroy infested leaders when their removal and destruction can be done economically, such as during Christmas tree shearing operations. Do this before the adults emerge from the affected shoots.

Destroy heavily damaged or worthless trees with large moth populations.

Future seed source investigation and studies of the responses of the different pine species to various soil factors, for example soil pH, are needed. They may well provide a basis for more specific recommendations.

SUMMARY

The Zimmerman pine moth, *Dioryctria zimmermani* (Grote), first discovered in this country in 1877, is a native forest pest found in most, if not all, of the northern United States and Canada. This investigation has clarified obscurities in its biology and ecology. For the first time, the mating habits, oviposition, eggs, and reproductive potential of the insect are described. In addition, information concerning damage, seasonal history, and host and stand conditions favorable to the insect are given.

Terminal infestation of pines may result in breakage of the tops and ultimate ruination, or may produce forking. Trunk infestation may result in partial or complete girdling and death of parts above the girdle. Current terminal attacks may be recognized after June or July by brown flags that are the result of tunneling or girdling of the branches. Trunk infestations are indicated by resin masses on the trunks.

Under favorable conditions, all pine species may be heavily attacked. Exotics, such as Scotch pine, however, appear more subject to heavy infestation and damage than most native pines. Species composition, whether pure or mixed, does not appear to affect the population level of the moth materially.

The level between 6 and 15 feet seems to provide the most favorable conditions for trunk infestations. Although all faces of trees are subject to infestation, examination of trunk sections revealed a decided trend toward heavier infestation on south and west sides.

Five different kinds of larval parasites were found and identified. During the period of this study, however, parasites were not a highly significant factor in mortality. Predation was not observed under field conditions.

Dispersal of the moth in Illinois has resulted from transportation of infested ornamental pines and by moth flight.

In general infestation increased with decreasing density of stand. A tendency for pruning of live branches to increase the chances of infestation was suggested, but conclusive proof must await subsequent studies. Plantations located 5 miles or more from sources of infestation, particularly if toward the prevailing winds, may escape infestation for several years. The character of the ground vegetation, litter depth, aspect, or slope did not seem to affect the degree of infestation in the plantations intensively studied. Within the range of high susceptibility, neither diameter nor differences in height had any influence on the degree of infestation.

Soil type appears to influence the level of moth infestation only indirectly by affecting the density of stand.

The terminals of trees are seldom successfully attacked until they reach a height of 4 to 5 feet. Successful and damaging attacks on the trunks were not observed until the bark became more than 0.15 inch thick.

New resin masses may serve as an index to the relative abundance of moths. A comparison of the number of new and old resin masses may be used to determine the rate of increase of the moth within a plantation from one year to the next.

Examination of the trunk cross sections showed that 1948 was the peak year of pine moth population in northwestern Illinois. In general the population has increased the season following a year when below normal precipitation occurred and has decreased in years following above normal precipitation. Exceptions indicate that other environmental resistance factors also operate to determine abundance, as would be expected in a complex community. No correlation was found between population fluctuations, the average monthly temperature, or temperature extremes.

Wise management may minimize the damage the moth causes in plantations. For recommendations concerning management, see page 35.

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ACKNOWLEDGMENTS

Special acknowledgment is due S. A. Graham, University of Michigan, for suggestions during the entire course of the study and for review of the manuscript. Acknowledgment is also made to the following individuals: J. N. Spaeth for advice and review of the manuscript; and W. P. Hayes for many suggestions during the early years of the study, both of the University of Illinois; to other University of Illinois colleagues for contributions to the field and laboratory phases of the project; to M. W. Sanderson, Illinois State Natural History Survey, for identification of moth specimens; and to personnel of the Division of Forest Insect Identification (of the former Bureau of Entomology and Plant Quarantine) and to the personnel of the Insect Identification and Parasite Laboratory of the Agricultural Research Service, both of the U. S. Department of Agriculture, for identification of moth and parasite specimens. A report of this investigation was submitted to the faculty of the Horace Rackhan School of Graduate Studies of the University of Michigan as partial fulfillment of the requirements for the Ph.D. degree.

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